Vol. VII, No. 2, Summer 1959

research trends

CORNELL AERONAUTICAL LABORATORY, INC., BUFFALO 21, NEW YORK

Hypersonic Flight in the Laboratory

by ROGER C. WEATHERSTON

Introducing the Wave Superheater — An Innovation in Hypersonic Wind Tunnels

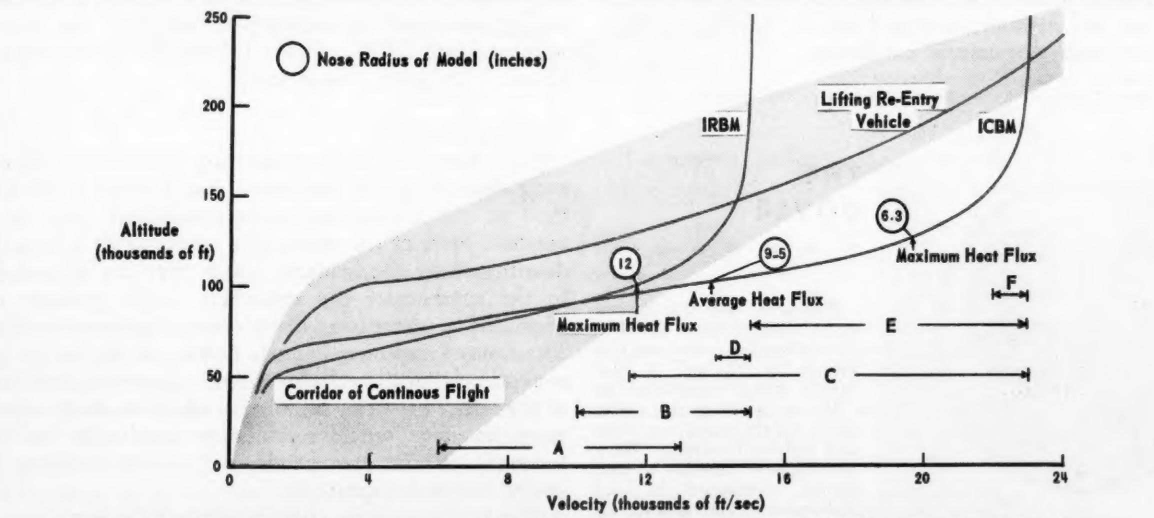
We learn as children that "shooting stars" are in reality small meteorites burning and evaporating as they fall at hypersonic velocities into the earth's dense atmosphere. Today, man seeks means to send missiles, space ships and hypersonic gliders through the meteorites' paces. The problems of tolerating the extreme temperatures present a great challenge to his ingenuity.

An intercontinental ballistic missile, for example, enters the atmosphere at the end of its flight path with sufficient kinetic energy to vaporize ten times its weight in water! If such a body is to survive atmospheric re-entry, most of its energy must be transferred to the surrounding air. The fate of all re-entry missions hangs on a delicate balance between heat absorption and dissipation.

Heretofore, to prove a design within the correct ultimate environment, the only way has been to build the bird, fly it, and observe its behavior by techniques involving telemetry and recovery from the sea — a tedious, costly, and frequently frustrating procedure. Cornell Aeronautical Laboratory has devised a new experimental tool, the wave superheater, which simulates for approximately full-scale models in the laboratory the extreme conditions of hypersonic flight. Initial studies and experiments have been sponsored by the Air Force Office of Scientific Research; the hypersonic research apparatus is presently being developed and built for the Advanced Research Projects Agency with the Air Force Arnold Engineering Development Center serving as contracting agency.

Simulation Capabilities of the Superheater

The high temperatures associated with hypersonics establish the importance of the temperature-generating



A: Environmental temperatures, pressures, and heat fluxes in the Mach 6 to 13 range duplicable in wave superheater test sections of 1 to 3 ft.^{2} area.

B: Realistic Reynolds numbers obtainable in wave superheater test sections of 2 to 10 ft.^{2} area for aerodynamic and heat transfer studies on slender lifting re-entry bodies.

C: Environmental IRBM and ICBM stagnation point heat fluxes duplicable in test sections on models of the indicated nose radii and at 2500°R surface temperature.

D: Electrical conductivity of shock layer on IRBM reproducible in air in the wave superheater test section for radar cross-section studies on near full-scale models.

E: Electrical conductivity of shock layer on lifting re-entry vehicles reproducible in air or air plus argon in the wave superheater test section for radar cross-section and communication studies on large-scale models.

F: Electrical conductivity of shock layer on ICBM reproducible in air-argon mixtures in the wave superheater test section for radar cross-section studies on large-scale models.

FIGURE 1 — Capability of the 9000°R Wave Superheater with respect to typical hypersonic re-entry environments.

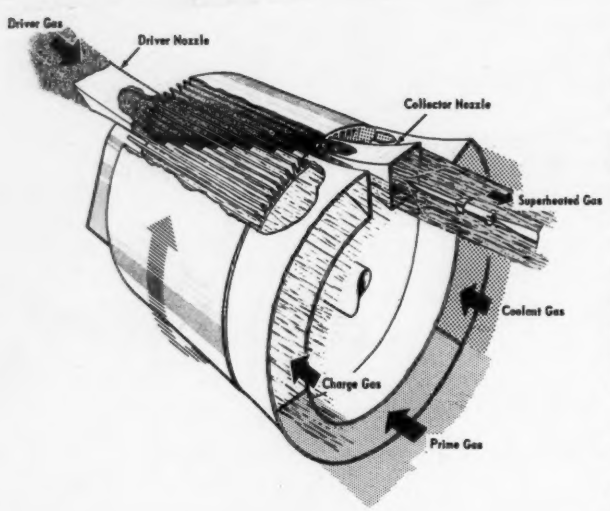


FIGURE 2 —**Rotor and nozzles of a Wave Superheater.**

characteristics of simulation devices. The temperature capabilities of the wave superheater, now in the 5000°R* to 10,000°R range if air is the test gas, are high enough for most hypersonic studies. Even higher temperatures can be obtained if the test air is diluted with argon. For example, a mixture of air and argon in equal amounts can be heated to 12,000°R, about the maximum temperature encountered by ICBM's. Pure argon can be heated to 20,000°R.

Temperature, however, is by no means the only important simulation parameter. In most instances, pressure and density simulation are equally important. In these respects the wave superheater is outstanding. The test gas is greatly compressed so that, following expansion through a hypersonic nozzle to a test section, it has sufficient pressure and density to simulate correctly many hypersonic conditions.

*Degrees Rankine (°R) = Degrees Fahrenheit (°F) + 459

THE COVER

Research into the causes and elimination of the tire vibration phenomenon known as "thump" is currently being conducted at CAL in a program sponsored by the Goodyear Tire and Rubber Company. Here an engineer checks a new device, developed at the Laboratory, for measuring the forces which act upon a tire to produce "thump." Data obtained using this device will be correllated with actual road data. The tire is held in a fixed position and the metal plate moves under it at a slow speed. As the tire rolls along the flat plate, pressure of up to 1000 pounds may be applied. The radial and lateral force variations that exist as the tire rolls on the plate will be measured. Results of this research will eventually lead to an understanding of the physical reasons for tire thump and then to elimination of the causes.

In addition, the superheater supplies relatively large flows of test gas, making possible many tests on approximately full-scale models. Examples of typical studies that can be performed are: ablation of missile nose cones; testing of composite structures; aerodynamic and heat transfer tests on slender bodies at realistic ambient pressures and at Mach numbers of 5 to 15; radar and infra-red radiation measurements at simulated re-entry conditions. The spectrum of important hypersonic environments is so broad, however, that it cannot be encompassed by any single facility. The capabilities of the superheater overlap and thus complement those of other test devices in some ranges; in other important ranges it is unique.

Application of Test Results

Not only is the hypersonic regime more difficult to simulate than the subsonic and supersonic regimes, but also there is an essential difference in the application of test results to the actual vehicle. In the subsonic and supersonic flight regimes extrapolation of the results of scale-model wind tunnel testing to an actual vehicle has been accomplished very successfully by means of aerodynamic scaling laws. In the hypersonic regime, however, the aerodynamic scaling laws are more complex and, more often than not, are secondary to other aerophysical effects.

To complicate matters, these effects cannot be scaled in the same manner. Thus the theorists must learn how to evaluate correctly the aerophysical effects in which they are interested, using one or several test facilities. Then they must predict composite effects on a vehicle under actual trajectory conditions.

The large test section of the superheater facilitates many composite tests that cannot be accommodated in any existing facility. Such composite testing gives the engineer a means of checking aerophysical and aerostructural interactions. Figure 1 illustrates the test capabilities of the wave superheater.

Working Principles

High temperature gas-generating devices are inherently limited by the maximum temperature at which their structural integrity can be maintained. The temperature limit of the vulnerable components is largely determined by the loads to which they are subjected. In the superheater the structural design problem is alleviated by alternating many contact surfaces rapidly. The time of exposure of each surface to the hot gases is extremely small and there is no appreciable heating of the structure. The cumulative effect of many exposures, however, would result in an intolerable rise in temperature. To prevent this each contact surface is cooled between exposures.

The heat-generating characteristics of the superheater can be compared to those of a piston compressor. However, an ordinary piston compressor, such as that found in an automobile, increases the gas temperature by squeezing the gas which is trapped between the piston and the cylinder head. In the superheater, as in a shock tube, the gas temperature is increased by the rapid motion of the piston itself; no counterpart of the cyl-

inder head is required. The faster the piston moves, the more the gas is heated.

To generate hypersonic gas temperatures, the velocity of the piston must be thousands of feet per second. The difficulty of devising solid pistons to travel at this speed is quite apparent. Thus a gas, other than the gas to be heated, is used as a piston. This gas is called the driver gas. A light gas, which can move very rapidly, is chosen for the driver gas and, for superheater applications, either helium or hydrogen must be used.

The driven gas is usually air. If the air is diluted or replaced by other test gases that are easier to heat, then still higher superheater temperatures can be obtained.

Exploiting Shock Wave Heating

The heating phenomenon described above is known as non-steady shock wave heating. This phenomenon has been exploited in shock tubes and shock tunnels.*

In the superheater, shock wave heating is used to generate a continuous flow of high temperature test gas. This is accomplished by mounting many open-ended tubes, side by side, on the periphery of a drum that is rotated rapidly (Fig. 2). Each tube is operated like a shock tube which is activated cyclically once per rotation of the drum.

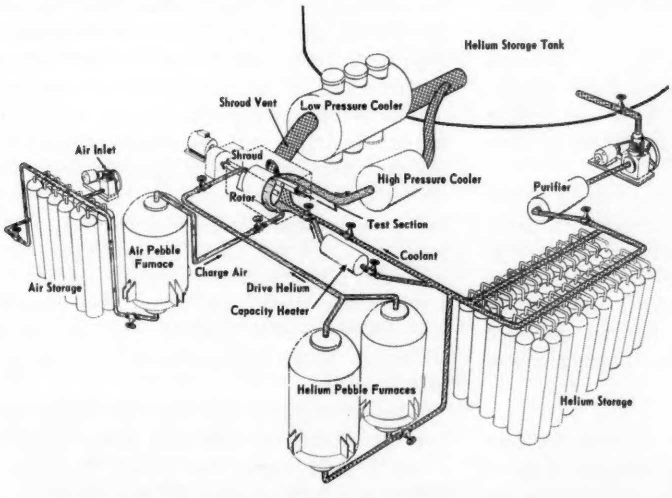


FIGURE 3 — **Flow chart for the 9000°R Wave Superheater.**

In its simplest form, a fixed charge nozzle and a fixed driver nozzle are placed at opposite ends of the drum. The charge nozzle, which spans many tube ends, charges each superheater tube with a low pressure test gas.

Each tube, upon completion of its charge phase, is immediately exposed to the driver nozzle. Opening each tube to the driver nozzle in the superheater corresponds to rupturing the diaphragm between the high and low pressure sections of a shock tube. The driver gas produces a shock wave in the test gas, compressing and heating it and driving it out of each tube, whereupon it is added to the discharge of adjacent tubes. More than one tube is discharging at any instant. The result is a continuous flow of superheated gas.

Conditions within the jet are essentially uniform. A model can be placed therein or the jet can be expanded through a collector nozzle to a higher supersonic velocity before it reaches the test specimen. After each tube passes the collector nozzle, it rotates into confluence with a nozzle which supplies a coolant gas that reverses the flow of the gas in the tubes. Upon rotating past the coolant nozzle, each tube is immediately exposed to a nozzle from which a priming gas issues.

This priming gas establishes a uniform flow through each superheater tube and minimizes the impedance to the test gas which is to follow. Essentially it sets up the cycle for continuous operation. The tube is now prepared for repetition of the cycle.

Earlier Uses of Principle

This idea of obtaining continuous flows by means of a rotating bank of shock tubes is not new. Brown, Boveri and Company was the first to use this principle. Refinements in the theory of wave machinery were later studied at Cornell University. Recently the I.T.E. Circuit Breaker Company has been exploiting the same principle on direct-acting energy exchangers.

The application of wave-type machinery to high temperature gas generation was investigated by CAL for certain types of chemical fixation processes. It was later suggested that this type of machinery could also be used to generate continuous flow of high temperature air for hypersonic test purposes.

The present superheater study at CAL is directed toward the analysis, design engineering and the construction of a specific machine which can process about ten pounds of air per second. About 4.3 pounds of this air can be collected without contamination and expanded to a test section, at 9000°R stagnation pressure for durations of 15 to 30 seconds. The length of the run is limited only by the storage capacity of driver and charge gases.

The rotor of the 9000°R wave superheater has 280 quasi-rectangular tubes, 0.55 inch wide, 1.43 inches high, and 66 inches long. The mid-heights of the tube lie on a 2.5 foot radius about their common rotational axis. The steel rotor weighs about 12,000 pounds and is driven by a 1000 hp synchronous motor. The rotor revolves with a speed of 700 feet per second at the tube center. High tube speeds are necessary to collect the superheated air efficiently as it issues from the tubes. The rotor is preheated to about 1160°R to eliminate thermal stresses during starting. This temper-

---

*"A Problem in Measurement," Research Trends, Spring, 1958; "The Wings of Icarus," Research Trends, Summer, 1955.

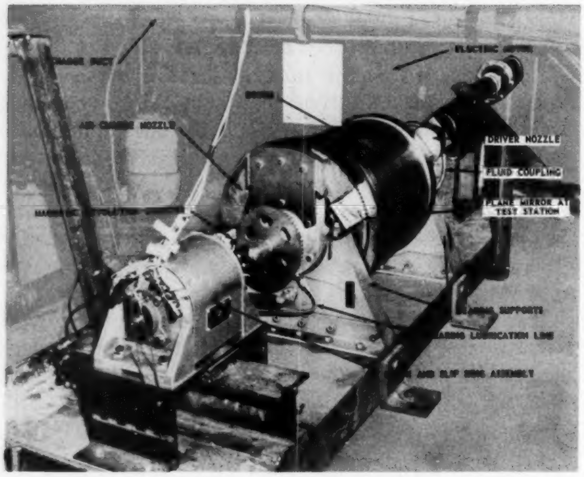


FIGURE 4 — The prototype Wave Superheater assembly.

ature is 100°R below the equilibrium temperature to be maintained at the tube wall during operation.

Operation of the wave superheater requires controlled flows of driver gas, charge air, and coolant and prime gases. Each of these gases, except the coolant gas, is heated in pebble furnaces before it enters the superheater proper (see Fig. 3).

Helium driver is stored in a bank of high pressure cylinders. The driver flow of the helium is regulated by means of a fast-response throttle valve that governs the pressure at which helium enters the pebble furnaces. The driver gas is preheated to 2160°R in the pebble furnace, after which it flows through a refractory-lined pipe to the helium driver nozzle.

The charge air is stored in high pressure flasks and is throttled to a reduced pressure at the inlet to a third pebble furnace. The air leaves this heater at 1800°R and flows through a refractory-lined pipe to the charge air nozzle. Another control valve further reduces the charge air pressure to maintain a desired pressure (slightly above one atmosphere) in the nozzle plenum.

Helium as Coolant and Prime Gas

Helium coolant is stored in a bank of high pressure cylinders and passes through a pressure-regulating valve before it enters the coolant nozzle. The pressure of the coolant gas determines the coolant flow rate which in turn governs the thermal equilibrium temperature of the rotor. Helium is also used as the prime gas. It is heated to 1260°R in a separate heater, then throttled to near one atmosphere at the prime nozzle.

About 70 pounds of helium are required for driver, coolant and prime gases for each second of superheater operation. Helium is not expandable at these rates, and therefore it must be recovered and purified. To accomplish this it is necessary to enclose the rotor and nozzles inside of a shroud.

During operation, the collected gases flow from the shroud through a large pebble cooler. They terminate in a 150,000 cubic foot diaphragm storage tank. This tank is essentially a bag which is collapsed before the run and expands to receive all of the reclaimable gases at atmospheric pressure during the run. After the run, the captured helium is separated from the air, compressed, and stored in a bottle farm for reuse.

Experiments with a Prototype Wave Superheater

A prototype wave superheater has been constructed at CAL under sponsorship of the Air Force Office of Scientific Research to test the gasdynamic principles in operation and to gain experience with this type of wave machinery. The prototype superheater does not generate temperatures high enough for hypersonic testing but it is adequate to demonstrate conclusively the principles of superheater operation.

The prototype superheater (Fig. 4) is one foot in diameter and 16 inches long. It has 108 tubes approximately ¼ inch square. Its operational speed is 4500 rpm. Unlike the 9000°R wave superheater, the prototype rotor, driver gases and charge gases are not preheated. The prototype superheater is primed for cyclic operation with the same gas as the charge gas. Thus, these phases are combined and only a single nozzle is required. No coolant gas is required for the prototype machine. In all, this machine is simple — yet consistent with the design objective.

The most important purpose of the prototype superheater program was to compare the temperature output of the test gas with the temperatures predicted from theoretical gasdynamic calculations. Such a comparison gives a valuable index of the performance of the prototype superheater and provides a basis for predicting the performance of high-temperature superheaters.

The prototype superheater was operated over a wide range of driver gas pressures, which determine the temperature of the test gas. Helium and hydrogen driver gases and air and argon test gases were used. The performance agrees well with theoretical prediction and supports the belief that a high-temperature superheater will also operate at or near its predicted value. It is noteworthy that from room temperature driver gas and charge gas a 2900°R test gas temperature was obtained. When argon was used as a charge gas, 5000°R was obtained.

The prototype superheater provided a means of testing the effects of hydrogen when used as driver gas. From a gasdynamic viewpoint, hydrogen is a better driver gas than helium. From a safety viewpoint, however, hydrogen is at a disadvantage.

The most significant result of the tests of the prototype superheater was that operation for as long as 30 seconds did not increase the temperature of the tube walls, even though the walls had been exposed to generated gas temperatures thousands of degrees higher than the surface temperature.

Construction of the 9000°R wave superheater is now under way. When completed, this experimental tool will provide a new capability for simulating the conditions of hypersonic flight.

REFERENCES

W. E. Smith and R. C. Weatherston, Studies of a Prototype Wave Superheater Facility for Hypersonic Research, CAL Rept. No. HF-1056-A-1, AFOSR TR 58-158, Dec. 1958.

R. C. Weatherston et al, Gasdynamics of a Wave Superheater Facility for Hypersonic Research and Development, CAL Rept. No. AD-1118-A-1, AFOSR TN 59-107, Feb. 1959.

Plastic Foams . . . :

by HAROLD M. PRESTON

When eating a piece of bread, cake, or even meringue pie, few consider the astonishing resemblance these foods have to a new lightweight plastic material — polyurethane foam. These foams have a uniform, non-connecting cellular structure and are generally white or slightly yellowish. They may be flexible or rigid, or have varying degrees of flexibility or rigidity.

The new plastic foams are strong, resist high temperatures well, are insect and mildew repellent, and are excellent insulators against sound and heat. These desirable properties have already led to applications in the aircraft, automotive, railroad and construction industries.

Foams Originally German

Although rigid polyurethane foams had German origins in about 1941, it was not until shortly after World War II that this country began to investigate their use for aircraft structural applications and radomes. Structural applications include stiffening by filling of void spaces in the wings, rudder, elevators, and ailerons of aircraft to produce strong lightweight members. Fabrication of these parts was rapidly simplified by a process known as "foaming-in-place." After foam ingredients are mixed, the batch is poured into the cavity to be filled. The mass expands and fills the void in a short time. The aluminum skin of the aircraft acts as the mold, and the foam acts as its own adhesive, adhering to the surface so well that the foam will break under stress before the aluminum-polyurethane bond.

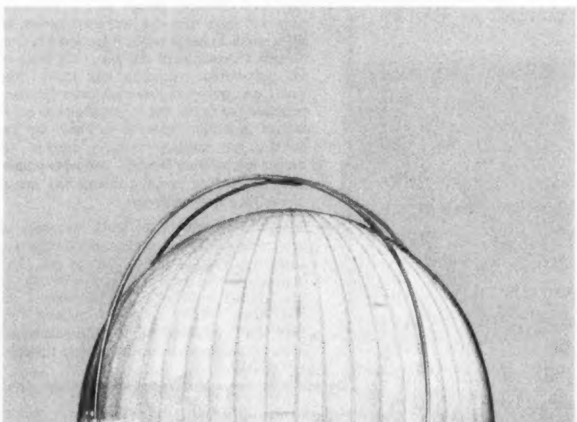
It is not necessary for the polyurethane to be foamed in place. In many cases it may be advantageous to use prefabricated foam, that is, sandwiches precut to fit in certain areas. In a similar manner, the foam itself, without any surface coating, may be cut to size and then fastened into the desired area. Outer skins or panels may then be nailed, bolted or glued directly to the foam.

Polyurethane foams burn somewhat like wood. However, when flameproofing ingredients are introduced into the foam they make it self-extinguishing without any deleterious effects to the foam properties. Self-extinguishing in this sense means that when the ignition source is removed, the flame will go out within a few seconds.

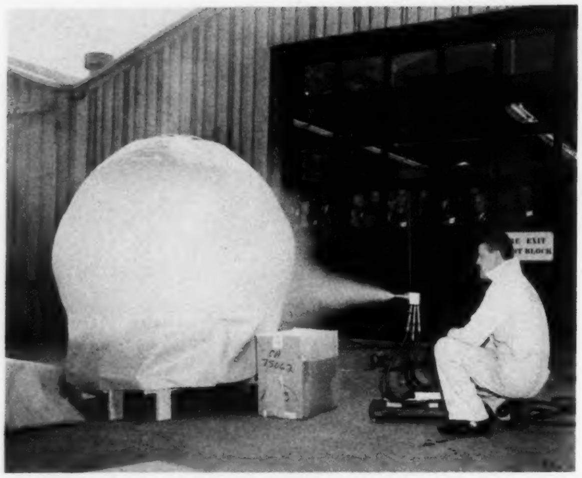
Advanced techniques now make it possible to apply foam to virtually any surface by means of a spray gun. Metering pumps insure delivery of the critical amounts of resin and foaming agent to the gun. There, the two components are mixed and forced through the nozzle by compressed air. Proper catalyzing of the resin will cause immediate expansion and rapid setting as soon as the mixture hits the surface of the object being sprayed. Using this system it is possible to spray such large areas as walls and large radomes without recourse to molds and forms.

Various types of foams may be prepared by proper selection of the polyester resin; included are strong rigid foams, tough elastic foams, soft flexible foams, and even spongy water-absorbent foams. One of these, strong rigid foam for lightweight structural applications, has received considerable attention at CAL during the past seven years.

An early disadvantage of foams was that in an operating environment of 200-250°F many of the



A proposed device for spraying foamed-in-place plastic on large structures.



Polyurethane foam being sprayed on a revolving model.

desirable properties were lost, particularly strength. Foams would soften, becoming spongy and rubbery. With the sponsorship of Wright Air Development Center, Cornell Aeronautical Laboratory undertook a foam development program with a view toward increasing the service temperature range of polyurethane foams. Various resin systems, copolymers, foaming agents and additives were formulated and tested. At the end of this program a resin system* had been developed which would retain more than half of its room temperature strength at 400°F.

Foamed Wings

With the solution to this problem came more uses for polyurethane foams. One use was the fabrication of a large wing structure for a drone target plane. The wing had a glass-fibre reinforced laminate skin and foamed core, and weighed about 99 pounds, compared with approximately 110 pounds for the same size aluminum wing. In static test the plastic foam sandwich wing took 165% of design load, compared with 110% of design load for the metal wing.

This high-temperature foam was also used to fill hollow compressor blades for wind tunnels. Such blades normally reach temperatures of 300°F, far beyond acceptable limits for other types of foams. Foam-filled compressor blades have been in operation for over three years without failure. They have proved to be better than the conventional blades for damping vibration and for sound absorption.

In sandwich radomes glass-fibre reinforced laminates are used for the outer and inner walls with a layer of foam between them. A highly desirable property of the foam when used in this particular application stems from its nearly perfect transparency to radar wave transmission.

A current project for the Air Force is the fabrication of a radome of 55-foot diameter composed entirely of rigid polyurethane foam. To perfect a technique useful in spraying an object this size, several small prototypes were sprayed by hand. Later the radome was mounted on a turntable and the spray gun was fixed in place while the dome rotated. Different areas are covered by moving the gun up or down. Several satisfactory radomes were made in this fashion.

In order to cover the 55-foot radome with foam, a new set of engineering problems must be solved. For that reason, a full-scale version is to be built and tested at the Cornell Aeronautical Laboratory. Several characteristics of polyurethane foams must be taken into consideration prior to open air spraying. For example, a strong wind will affect the atomization and direction of the foam spray. Rain or a day with high relative humidity will result in the development of a poor foam. Water present under these conditions will react with the isocynate to give unpredictable results. Thus, a "good" day is required for this type of operation.

Successful application of foams led to the question of whether these materials could be used in the building industry. Insulation qualities, combined with its high strength/weight ratio, would seem to make foams ideal for filling interwall spaces and other voids in houses. A major disadvantage at first was the high cost of foams as compared to such other insulating materials as rock wool. The difficulty of preparation of the foam itself was also a disadvantage until the advent of the diisocyanate prepolymer and

What Is Polyurethane Foam?

The major ingredients of polyurethane foams are (1) polyester resins, obtained by mixing a glycol or triol with a dibasic organic acid, and (2) a diisocyanate, generally tolylene diisocyanate. Upon mixing, the diisocyanate reacts with the free hydroxol groups of the polyester resin, and this forms a polyurethane. This reaction may be considered of the chain extension or addition polymerization type, yielding a rather viscous liquid. Production of foam from the liquid polyurethane may be accomplished by several methods. In all methods a gas is generated and trapped by the solidifying material.

1) Any free carboxyl groups in the polyester resin will react with the isocyanate groups to form amide linkages with evolution of carbon dioxide. Formation of this gas in the body of the polyurethane produces the foam. The heat generated by the reaction raises the temperature and causes the polyurethane to polymerize to a rigid material in which the gas bubbles are trapped. Success depends on proper temperature control. A similar process occurs in baking bread, although the source of the gas is quite different.

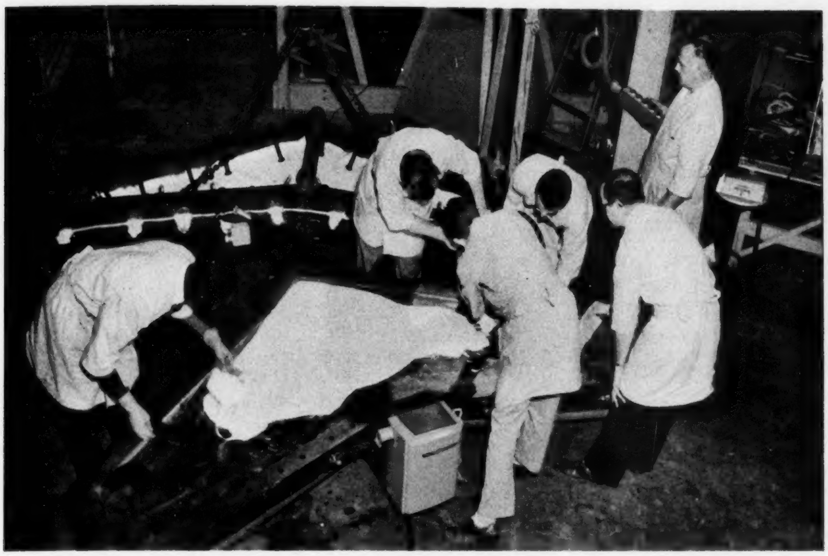
2) A second method adds small amounts of water, which reacts with the diisocyanate, thereby generating carbon dioxide gas. This method may be used as a supplement to the first method described and is necessary if the resin being foamed has a low carboxyl content. Again, the reaction develops heat which causes the polymerization to a rigid material. Reaction of water with diisocyanates liberates carbon dioxide and forms disubstituted ureas which become incorporated in the polymerized resin.

Excellent foams have been obtained using either method or combinations of the two. However, several disadvantages were inherent in both systems. The diisocyanate is a lachrymator and is generally unpleasant to use. In addition, traces of moisture quickly destroy its reactivity. Reaction time between the polyester resin and diisocyanate to form foams required from 45 minutes to one hour with constant supervision. Positive temperature control for large mixes is necessary to prevent premature foaming.

In the past several years, various modifications of the foaming agent have been made which eliminate most of these undesirable properties. Diisocyanate is mixed with a triol to form a polyurethane containing excess diisocyanate. Since neither carboxyl groups nor water are present no foaming results at this point and the reaction is one of addition. Water and a polymerization catalyst are added to the polyester resin and the mixture is emulsified. The modified diisocyanate and the emulsified resin are now mixed together and foaming and polymerization occur. The reaction time is decreased to one or two minutes, depending on type and amount of catalyst used, and no temperature controls are necessary. Density of the foam is controlled by the amount of water and modified diisocyanate added. Foams have been prepared having densities ranging from slightly under 2 lb/ft^3 to over 30 lb/ft^3.

---

*Specifically, a maleic anhydride-triallylcyanurate copolymer resin system.



An early use of foamed-in-place plastic cores. When encased by tough, glass-reinforced laminate skins, these sandwich wings offer a high strength-to-weight ratio.

premix resin. With this system, it is necessary only to insure that the proper ratio of ingredients is being delivered to the mixing chamber of the spray gun or other equipment being used. The cost difference between foams and other structural materials is gradually being reduced as more uses for foam are found and production increases.

Considerable attention has been given to the various problems and properties of polyurethane foam cores for sandwich construction. A variety of materials for skins have been tested, including metal, wood, fiberboard, asbestos and glass-reinforced plastic, with a range of foam densities. Mechanical properties of large test panels have also been investigated. An advantage in this type of construction is the insulating property of the foam. All stresses are carried by the outer "skins" of the sandwich structure, or in ultimate terms, the actual walls of the house or building. This is in contrast to the use of foams in aircraft, where the foam actually is required to carry part of the load by stiffening the skin.

Other Foams Being Developed

Although this discussion has been restricted to the uses of rigid foams, there is a group of similar foams having different properties. Polyether foams, for example, are more resilient than those based on alkyd resins. Vinyl foams of various types have also been developed for similar uses.

As research continues, new types of foams are being discovered which further expand the field. New applications for flexible polyurethane foams are being developed for packaging, bedding, and rug underlays. Successful use has been made of rigid polyurethane foam in refrigerator trucks and railroad cars.

Research has now brought about such increased use of isocyanates for foam that the demand is expected to rise from 1 million pounds in 1955 to 94 million pounds in 1960.

ABOUT THE AUTHORS

ROGER G. WEATHERSTON, author of "Hypersonic Flight in the Laboratory," has been a member of the Laboratory's Aerodynamic Research Department since 1948. He first served as an Associate Research Mechanical Engineer; in 1957 he was made Head of the Gasdynamic Development Section. Earlier this year he was named principal research engineer.

He is the author of several reports and papers on gasdynamic effects of heat addition of flowing gases, propulsion device ejectors, supersonic wind tunnels and nonsteady gasdynamic machinery.

Mr. Weatherston received a bachelor of science and master of science degree in mechanical engineering from Purdue University.

Before his service with Cornell Aeronautical Laboratory he was employed by the Curtiss-Wright Corporation as an aerodynamicist. He also served in the Air Force as a navigator. He was discharged as lieutenant in 1945 after two years' service.

HAROLD M. PRESTON, JR., the author of "Plastic Foams," has over five years experience in the development of various plastic foams. His background includes earlier work in the development of foaming resins, heat resistant and laminating resins, vapor phase chromatography, gas analysis, ultra violet spectrophotometry and solar radiation work.

Mr. Preston received a B.A. in Chemistry from the University of Buffalo in 1951. He joined the Laboratory the same year as an assistant research chemist in the Materials Department. Since that time he has completed three years of graduate study in chemistry at the University of Buffalo.

Prior to joining the Laboratory, Mr. Preston worked for the Marlin Rockwell Corporation. He served in the U.S. Army from 1943-1946 and was discharged with the rank of Staff Sergeant.

Mr. Preston is a member of the American Chemical Society.

RECENT CAL PUBLICATIONS

The Laboratory invites requests for its unclassified publications as a public service. Supplies of some publications are limited; and those marked with an asterisk may be distributed only within the United States. Please direct your request to the Editor, Research Trends, Cornell Aeronautical Laboratory, P.O. Box 235, Buffalo 21, New York.

"SHOCK TUBE STUDIES OF THE REACTION KINETICS OF ALIPHATIC HYDROCARBONS," Glick, Herbert S.; Paper presented at the Seventh International Symposium on Combustion, London and Oxford, England; August 1958; 10 pages.

Kinetic properties of the decomposition of aliphatic hydrocarbons at very short reaction times (0.25 millisecond to 4 milliseconds) are reported. The experiments covered a temperature range varying from 1000°K to 3500°K.

"A STUDY OF THE ATTAINABLE RANGE OF HELICOPTERS," Adler, Abraham C. and Holm, Helen S.; Paper presented at the American Helicopter Society Fifth Annual Western Forum; September 1958; 45 pages.

A study has been made of the effects of parasite drag, mean rotor lift coefficient, and mean rotor blade tip Mach number on the maximum lift-drag ratio and range that can be achieved with large helicopters. The results indicate that a significant improvement in maximum range may eventually be possible.

"DIGITAL RECORDER FOR WIND TUNNEL DATA," MacArthur, Robert C. and Unger, William J.; Reprinted from Electronics, Vol. 31, No. 49; December 1958; 4 pages.

Force and pressure data from wind-tunnel models are read out on punched cards and printed forms to three-digit accuracy while tunnel tests are in progress. Basic system sections may be adapted for digital recording of voltages, currents and resistances as well as recording of frequency and time-coded data.

"SUMMARY OF INSTRUMENTATION DEVELOPMENT AND AERODYNAMIC RESEARCH IN A HYPERSONIC SHOCK TUNNEL," Wittliff, Charles E. and Rudinger, George; CAL Report No. AD-917-A-2; August 1958; 65 pages.*

Analytical and experimental research devoted to devising, developing and applying instrumentation and techniques to measuring aerodynamic forces and heat transfer rates on a cone at an angle of attack are reported.

"COOLING TECHNIQUES FOR EQUIPMENT RELIABILITY," Welsh, James P.; Paper presented at the First Symposium on Military Electronics Reliability and Maintainability, Rome Air Development Center, Rome, N. Y.; November 1958; 29 pages.

This paper presents limited data pertinent to the measured gains in reliability achieved through adequate cooling. The modes of heat flow through and from heat-producing parts are discussed, together with cooling techniques peculiar to Air Force ground electronic equipment.

"THE FLUTTER OF LOW-ASPECT-RATIO WINGS," Targoff, Walter P. and White, Richard P., Jr.; I.A.S. Preprint No. 858; October 1958; 39 pages.

This preprint presents a numerical procedure by which the low-aspect-ratio theory formulated by Lawrence and Stone can be used to calculate the flutter characteristics of any low-aspect-ratio wing having a straight trailing edge.

"LONG-TERM REQUIREMENTS AFFECTING PRESENT AIR TRAFFIC CONTROL PLANNING," Stevens, Robert M.; Paper presented at the Eleventh International Air Transport Association Technical Conference, Monte Carlo, Monaco; September 1958; 14 pages.

This paper discusses three characteristics of air traffic which are changing enough to alter significantly the requirements placed on aviation facilities.

"ALUMINUM ALLOY CORROSION EVALUATION," Gillig, Franklin J.; CAL Report No. KC-1042-M-11; September 1958; 22 pages.

Five aluminum alloys were evaluated to determine the effects of possible aircraft carrier deck environments on their mechanical properties and corrosion resistance.

"AMPLITUDE AND PHASE DISTORTION IN FM COMMUNICATION AND TRACKING SYSTEMS DUE TO MULTIPATH INTERFERENCE," Becker, Harold D.; Reprinted from the Second National Convention on Military Electronics Proceedings; 1958; 8 pages.

This paper presents the results of a theoretical and experimental investigation of the distortion in the output of an FM receiver when a single-tone frequency modulated signal arrives at the receiver over two paths which differ in length. In particular, this study is concerned with the amplitudes of the harmonics of the sinusoidal modulation signal and the phase error created in the fundamental component of the receiver output signal.

"TRANSITION PROBABILITIES FOR O_2 RADIATION IN THE NEAR ULTRAVIOLET," Wurster, Walter H. and Treanor, Charles E.; CAL Report No. QM-1209-A-1; August 1958; 18 pages.

Spectroscopic shock tube experiments are described, showing the dominant role of the Schumann-Runge band system of oxygen in determining the ultraviolet absorptive properties of high-temperature air (2500 - 4500°K). The absorption by pure oxygen in this temperature range has been investigated at high resolution.

"TECHNIQUES OF COOLING ELECTRONIC EQUIPMENT," Welsh, James P.; Reprinted from Electrical Manufacturing; November and December 1958; 19 pages.

This paper presents methods and techniques of temperature measurement and control, as well as practical methods of cooling specific electronic parts and systems.

"SUMMARY OF CORNELL AERONAUTICAL LABORATORY TIRE TEST DATA," Fonda, A. G. and Radt, H.; CAL Report No. YD-1059-F-2; October 1958; 49 pages.

The mechanical characteristics of the test tires are presented in thirty-nine figures and are briefly described with respect to properties of the standing and steady-state rolling tire, distance-transient behavior, and friction properties.

Requests for the following report will be relayed to the project sponsor.

"THE STUDY OF EROSION OF AIRCRAFT MATERIALS AT HIGH SPEEDS IN RAIN," Lapp, Roy R.; Thorpe, Donald H.; Stutzman, Raymond H.; and Wahl, Norman E.; CAL Report No. PC-962-M-36; November 1957; 274 pages.*

The results obtained on the relative rain erosion resistance, at subsonic speeds, of a large number of different types of materials, are reviewed in detail in this report.